AD-A034 454   AMERICAN UNIV WASHINGTON D C
                 RESEARCH ON ELECTROCHEMICAL ENERGY CONVERSION SYSTEMS.(U)
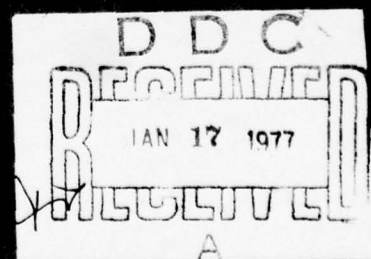   JUL 76   A A ADAMS, R T FOLEY   F/G 7/4

UNCLASSIFIED   DAAG53-76-C-0001
                                                                        NL

| OF |
ADA034454

END

DATE
FILMED

2 -77

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* Research on Electrochemical Energy Conversion Systems		5. TYPE OF REPORT & PERIOD COVERED Final Report. July 1, 1975 – June 30, 1976 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Adams, Alayne A. and Foley, Robert T.		8. CONTRACT OR GRANT NUMBER(s) DAAG53-76-C-0001
9. PERFORMING ORGANIZATION NAME AND ADDRESS The American University Washington, D. C. 20016		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1T161102A34A 03 100 EF
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia		12. REPORT DATE July 1976 13. NUMBER OF PAGES 24 + iii
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Electrochemistry, Fuel cell, Electrolytes,

Trifluoromethanesulfonic acid

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*
The project on electrochemical energy conversion systems has involved two tasks: the determination of the electrochemical behavior of low molecular weight hydrocarbons and alcohols as well as other possible fuels in aqueous trifluoromethanesulfonic acid and the examination of the electrochemical interaction of fuel cell reactants with platinum surfaces in aqueous trifluoromethanesulfonic acid.

The order of reactivity for low molecular weight alkanes was determined to be $C_3H_8 > C_2H_6 > n\text{-}C_4H_{10} > CH_4$ in trifluoromethanesulfonic acid monohydrate

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73
S/N 0102-014-6601

GREATER THAN

The same reaction order had been established previously for low molecular weight alkanes in inorganic acids such as HF, H_2SO_4, and H_3PO_4. In the case of each alkane the electrochemical activity in the sulfonic acid was significantly greater than that in phosphoric acid under the same conditions.

The electrooxidation of each alkane was evaluated over the temperature range from 95°C to 135°C.

The experimental data collected during this reporting period confirm the previous finding that trifluoromethanesulfonic acid monohydrate represents an improved electrolyte for the hydrocarbon-air fuel cell.

Unclassified

Research on Electrochemical Energy Conversion Systems

Final Technical Report

by

A. A. Adams and R. T. Foley

July 1976

to

U. S. Army Mobility Equipment Research
and Development Command

Fort Belvoir, Virginia

Prepared by

The American University

Washington, D. C.

Contract No. DAAG53-76-C-0001

DA Project/Task Area/Work Unit No. 1T161102A34A 03 100 EF

Approved for public release and sale

distribution unlimited

Unclassified

TABLE OF CONTENTS

SUMMARY

The project on electrochemical energy conversion systems has involved two tasks: the determination of the electrochemical behavior of low molecular weight hydrocarbons and alcohols as well as other possible fuels in trifluoromethanesulfonic acid monohydrate and the examination of the electrochemical interaction of fuel cell reactants with platinum surfaces in trifluoromethanesulfonic acid monohydrate.

The order of reactivity for low molecular weight alkanes was determined to be $C_3H_8 > C_2H_6 > n-C_4H_{10} > CH_4$ in trifluoromethane-sulfonic acid monohydrate. The same reaction order had been established previously for low molecular weight alkanes in inorganic acids such as HF, H_2SO_4, and H_3PO_4. In the case of each alkane the electrochemical activity in the sulfonic acid was significantly greater than that in phosphoric acid under the same conditions.

The electrooxidation of each alkane was evaluated over the temperature range from 85° to 135°C.

The experimental data collected during this reporting period confirm the previous finding that trifluoromethanesulfonic acid monohydrate represents an improved electrolyte for the hydrocarbon-air fuel cell.

FOREWORD

This research on electrochemical energy conversion systems has been sponsored by the U.S. Army Mobility Equipment Research and Development Command at Fort Belvoir, Virginia, under Contract No. DAAG 53-76-C-0001 with The American University.   The work was authorized under DA Project/Task Area/Work Unit No. 1T161102A34A 03 100 EF.

ii

LIST OF FIGURES

iii

1.0 Introduction

This is the final technical report on Contract No. DAAG 53-76-C-0001 sponsored by the U.S. Army Mobility Equipment Research and Development Command at Fort Belvoir, Virginia. The project entitled "Research on Electrochemical Energy Conversion Systems" consists of two technical tasks both of which are directed toward the investigation of the properties of trifluoromethanesulfonic acid monohydrate as an electrolyte for the hydrocarbon-air fuel cell.

Task I: The determination of the electrochemical behavior of low molecular weight hydrocarbons and alcohols as well as other possible fuels in trifluoromethanesulfonic acid monohydrate.

Task II: An examination of the electrochemical interaction of fuel cell reactants with platinum surfaces in trifluoromethane-sulfonic acid monohydrate:

The main effort during this reporting period was devoted to Task I.

2.0 Task I The Determination of the Electrochemical Behavior of Low Molecular Weight Hydrocarbons and Alcohols in Aqueous Trifluoromethanesulfonic Acid

2.1 Introductory

The previous study of trifluoromethanesulfonic acid monohydrate demonstrated the dramatic effect of the electrolyte on fuel cell performance (1). Hydrogen and propane electrooxidations were shown to support significantly higher current densities than those obtained in phosphoric acid and the reduction of air began from a higher open circuit potential. The net effect is a theoretical complete, energy producing cell substantially higher energy density than that available from the present state-of-the-art.

The rates of electrooxidation of the low molecular weight alkanes have been shown to follow the series $C_3H_8 > C_2H_6 > n\text{-}C_4H_{10} > CH_4$ in the common inorganic acid systems (2). It is of theoretical and practical interest to investigate this series of alkanes in $CF_3SO_3H \cdot H_2O$ to determine the relative electrooxidation characteristics. Further, from a technological standpoint, the detailed investigation of methane electrooxidation is of considerable importance due to the availability of methane as a high purity fuel.

2.2 Experimental

Electrochemical apparatus and techniques

The cell used for the experiments was a standard three-compartment cell. The cell used for the experiments on trifluoromethanesulfonic acid monohydrate shown in Figure 1 was of approximately 30 ml capacity. The working electrode in the central compartment of the cell consisted of a platinum wire mesh electrode of approximately 4.0 cm^2 real surface area spot-welded to a platinum wire lead. The counter electrode compartment was separated from the working compartment by a fritted glass disc. The counter electrode (left compartment, Figure 1) was platinized platinum mesh connected to a platinum wire lead.

The reference electrode system was separated from the working electrode compartment by inserting a fritted glass disc behind the Luggin capillary. The reference electrode is of the dynamic reference electrode design of Giner (3). This reference electrode system consists of two platinized platinum electrodes [A] and [B]. When a current density of 1 ma/cm^2 is impressed between electrode [A] and [B], H_2 is evolved from the cathode, [A], and O_2 is evolved from the anode, [B]. The cathode is kept 1 - 2 cm lower than the anode to prevent diffusion of O_2 from the anode to the cathode. Temperature control was achieved by maintaining the cell in an air oven.

The potential-time sequence shown in Figure 2 was used to determine the "real" surface area of the electrode. The pretreatment
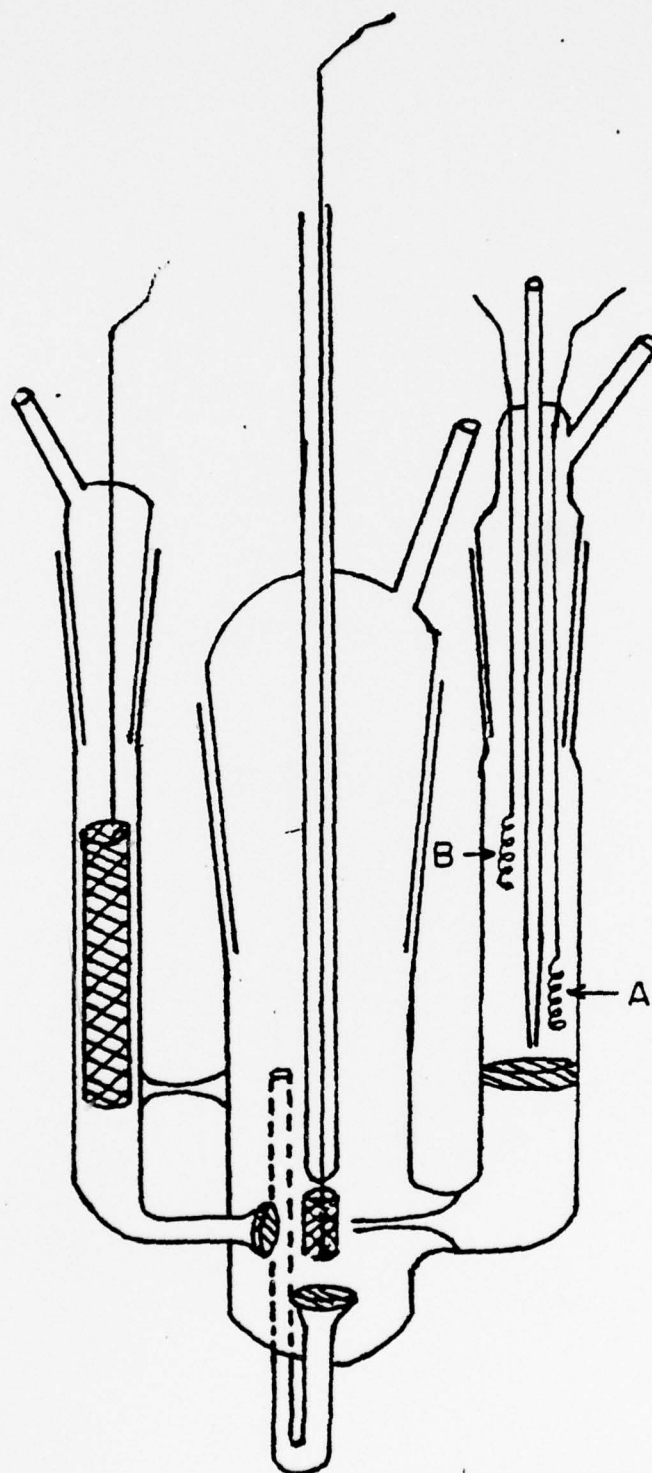
4

Figure 1.   Electrochemical cell used for experiments
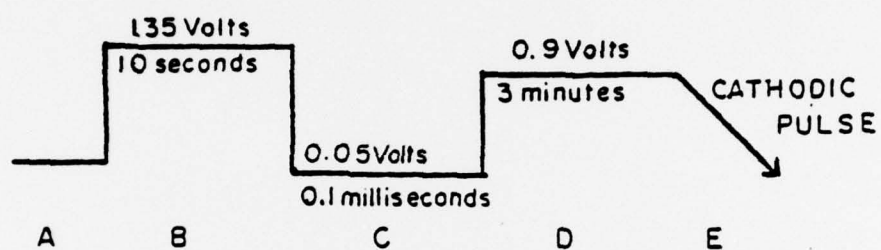with trifluoromethanesulfonic acid

Figure 2. Potential-time sequence used to determine
real surface area of electrodes.

steps are used to prepare a reproducible electrode surface for each measurement. During step B the electrode is brought to +1.35 volts which oxidizes oxidizable impurities on the electrode surface and forms a passive oxide layer on the platinum surface. The potential is stepped down to +0.05 volt, step C, where the oxide layer is reduced. The potential is then raised to 0.95 volt, step D, to desorb H atoms adsorbed at 0.05 volt. Step D was set at 0.95 volt after variations in measured surface areas were observed when potentials below 0.75 volt were used. Potentials above 0.75 volt gave reproducible values for the surface area. A cathodic galvanostatic pulse of 25 to 75 milliamps/cm^2 was applied, (step E), to measure the charge associated with the coverage of hydrogen. The maximum cathodic galvanostatic charge for depositing H atoms on a clean electrode prior to H$_2$ evolution, after correction for double layer effects, is 210 μcoulombs/cm^2. It is known that this value changes with temperature and electrolyte composition to some degree, however, within experimental limitations used here, the value of 210 μcoulombs/cm^2 may be used (4).

Current density vs. potential diagrams were constructed with measurements for helium, methane, ethane, and n-butane. Experiments with all gases were run at 95°, 115°, and 135°C. An automated electrochemical station, designed previously, was used to develop the current-potential diagrams (1). The schematic of the system is shown in Figure 3. The system consists of A, the programmable timing controller, B, the potential step device, C, the basic electrochemical system, D, the data acquisition system, and E, the computer to
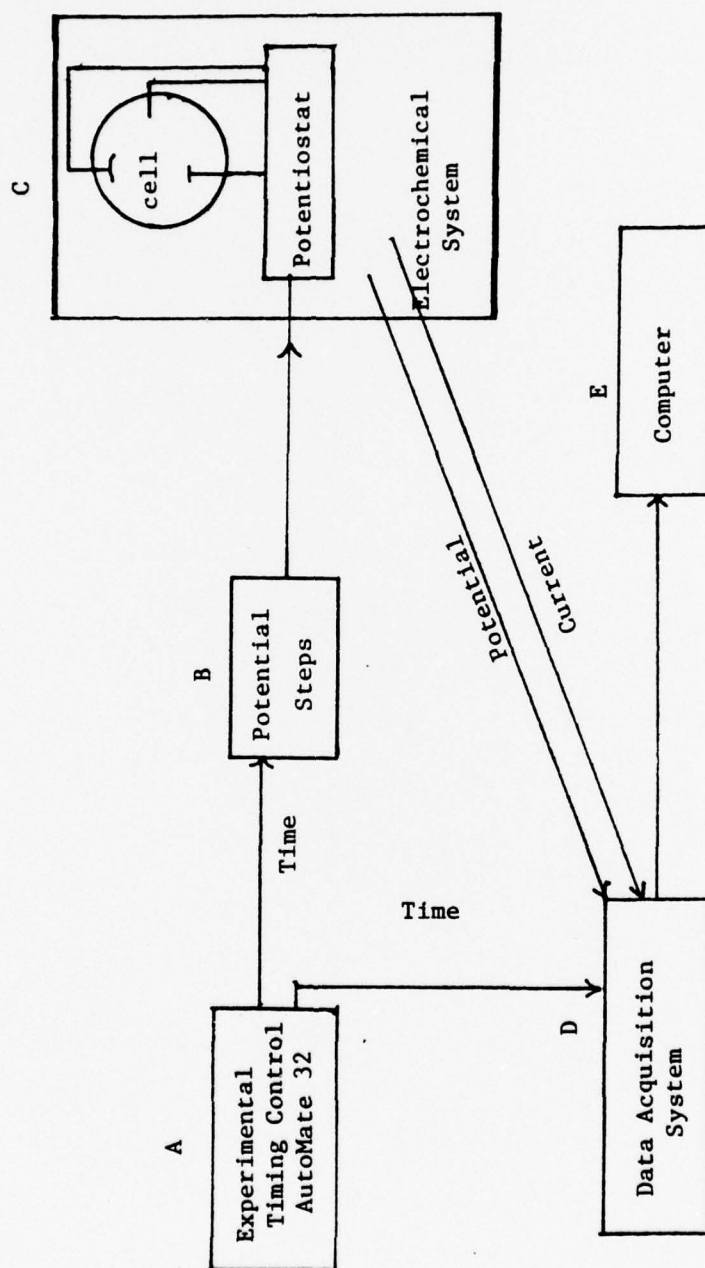
Figure 3. Schematic diagram of automated electrochemical station

process data.

The programmable timing controller, an AutoMate 32 (Reliance Electric Company, Cleveland, Ohio 44177), is a solid-state device having a stored program which controls outputs in a predetermined way in response to the action of the inputs. The major elements of the AutoMate 32 are shown in Figure 4. In addition to those shown, there is a manual programmer with its internal memory and processor which is used to program the Erasable Programmable Read Only Memory (EPROM). The major elements of the AutoMate 32 are A, the controller chassis, containing the power supply, processor and controller monitor; B, input cards; C, output cards; D, timer counter latch (TCL) cards; E, program memory module; F, communication interface and G, input and output blocks which connect with the input or output cards in the controller chassis. The analog timer elements (Model 325), mounted in the TCL card, are adjustable from 0.5 to 127.5 seconds per timer element. Times longer than 127.5 seconds are controlled by counter elements. Programming is done via a ladder diagram which symbolically represents the elements of the control circuit. The input devices and interlocking contacts are placed in the desired parallel or series combinations across the rung of the ladder with the last element on the rung being the output associated with the sequence.

The potential step device shown in Figure 3 has a variable base potential step and 2 times, 4 times, and 8 times this base step. These steps can be used individually, or in any combination, allowing 15 possible potential steps. These steps are programmed in any
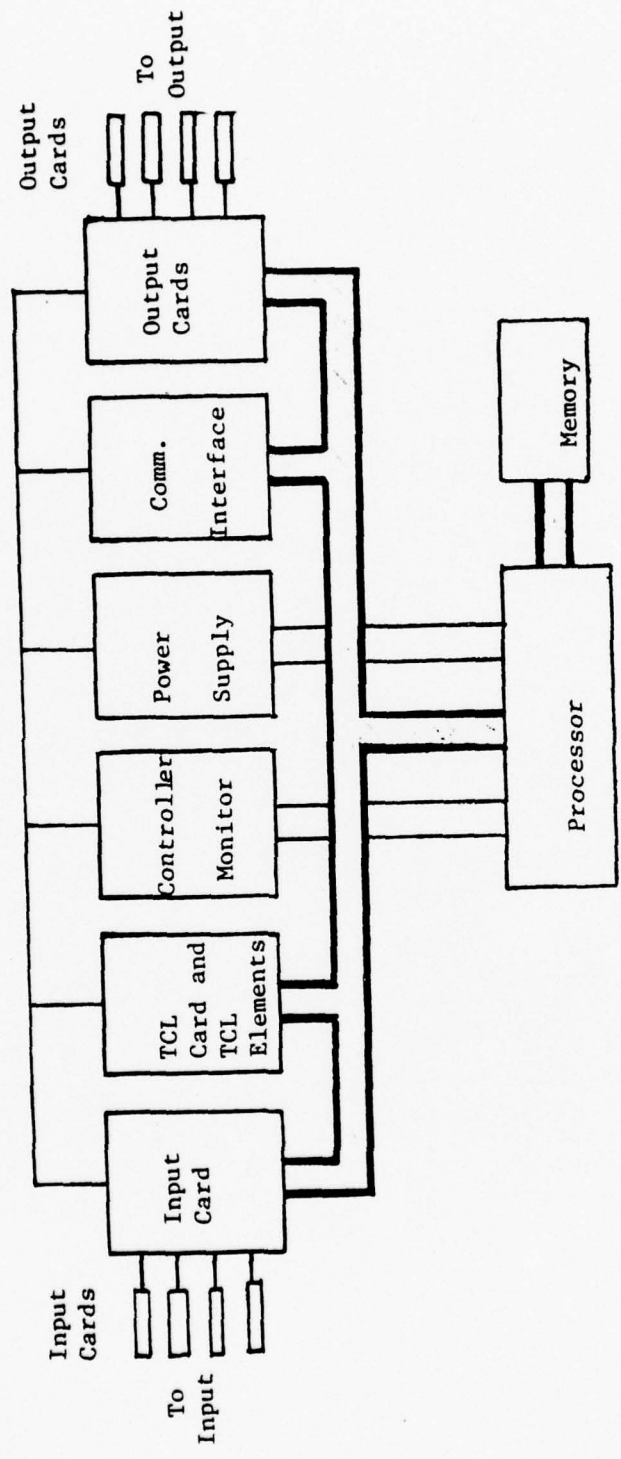
Figure 4. Major elements of Automate 32

sequence from the controller. If the base potential step is 10 mv a total of 150 mv may be algebraically added in 10 mv steps to the potential set in the potentiostat. If 50 mv is the base potential step, 750 mv may be added to the set potential. Initially the device has been used for development of current potential diagrams where time at each potential step is equal. However, it is possible to vary the time at any step or steps allowing great flexibility of the system.

The basic electrochemical unit is the potentiostat with function generator or galvanostat plugin and the electrochemical cell. This portion of the overall system can be used manually in the traditional manner or be tied to the controller for automated control.

The data acquisition system, Dymec DY-7061, (D in Figure 3) consists of a 25 channel input scanner (Model No. 2901B, Dymec Division, Hewlett Packard, Palo Alto, California), a digital clock (Model No. 3440A), a digital recorder (Model No. N39562A) and a paper tape punch (Model No. 5655). The data acquisition system scans up to 25 input signals, measures the dc voltage of each signal, and records the voltage measurements. This data system is adequate to record data for current-potential diagrams, but to cope with faster reactions, this portion of the electrochemical station will have to be updated. At this time, data are taken in eight channels, 2 for potential and 6 for current for a set period of time after equilibration time at a set potential (e.g., 30 seconds data recording after 5 minutes equilibration time.) For example, 18 current points and 6 potential points are recorded.

The computer (Xerox Sigma 2) processes the data, at present

stored on punch paper tape, to read potential and current density values. The current values over all channels scanned are averaged and divided by the real surface area of the electrode. The average potential values and current density values are output to the printer for future graphing of data. The graphing could be done via the computer by an addition to the computer program.

The entire system allows for automated control of the basic electrochemical system with data recorded and stored for future processing. This capability allows the basic system to be run overnight when no operator is available, or, particularly for current-potential diagrams, relieve the operator from the tedious task of taking data at prescribed intervals. Also, a greater number of current readings can be taken, allowing for greater precision in the current readings than is possible with a single reading by the operator.

Preparation of electrolytes

Trifluoromethanesulfonic acid monohydrate was prepared from trifluoromethanesulfonic acid (3M Corp., Lot 7 "Fluorochemical Acid FC-24") and water by the method of Gramstad and Haszeldine (5). Equimolar quantities of trifluoromethanesulfonic acid and water were added to a distillation flask. Fractional distillation was carried out with the fraction below 110°C collected and removed. The fraction above 110°C was collected as a white crystalline product with some viscous clear liquid. This fraction was distilled a second time with all material distilled below 150°C rejected and the fraction above 150°C retained for a third distillation. In the third distillation

only the fraction between 217-218°C (756.9 mm Hg) was retained as a
white needle-like crystalline product, trifluoromethanesulfonic acid
monohydrate. The $CF_3SO_3H \cdot H_2O$ was found to have a melting point of
33.8°C which agrees well with the value of 34°C given by Gramstad
and Haszeldine (5). No further purification was done before the
trifluoromethanesulfonic acid monohydrate was added to the
electrochemical cell.

Preparation and treatment of reactants

Helium, methane, ethane, and n-butane were used in different
experiments. Helium (AIRCO) was passed over hot copper turnings to
remove traces of oxygen before being passed into the cell. Methane
(Matheson, high purity), ethane (Matheson, instrument grade), and
n-butane (Air Products, instrument grade) were used without pretreatment.
All gas lines were heated so that the gas entering the cell was close
to the operating temperature of the cell.

13

2.3 Results and Discussion

The electrochemical behavior of helium, methane, ethane, and n-butane at a smooth platinum electrode in the $CF_3SO_3H \cdot H_2O$ electrolyte was investigated at various temperatures in the range of normal fuel cell operation. The experiments with helium provided background, or base line, data for the electrolyte. The electrooxidation of methane, ethane, and n-butane were compared with those obtained previously with propane (1). The comparison of results with methane and propane are of significance due to the general availability of methane. The most common impurity in commercial methane is ethane, so the evaluation of ethane is of importance. These compounds also result from the incomplete cracking of hydrocarbon fuels. It has been reported previously that n-butane does not electrooxidize with as high current densities as does propane in the inorganic acids (2). The electrooxidation of n-butane was investigated to determine if this decrease in current levels also held in $CF_3SO_3H \cdot H_2O$.

Electrochemical behavior of methane in $CF_3SO_3H \cdot H_2O$

Figure 5 summarizes the data for the electrooxidation of methane at 95°C, 100°C, 115°C and 135°C. The current carrying capacity of the electrode clearly rises with the temperature as would be anticipated. The open circuit potential shifted to a slightly lower value with the change in temperature from 95° to 135°C; a   total change of from 0.290 volt to 0.275 volt .
The current density at 0.5 volt at 135°C was 1.7 $\mu a/cm^2$ as compared with 8.2 $\mu a/cm^2$ for propane (1). Table I summarizes the open circuit
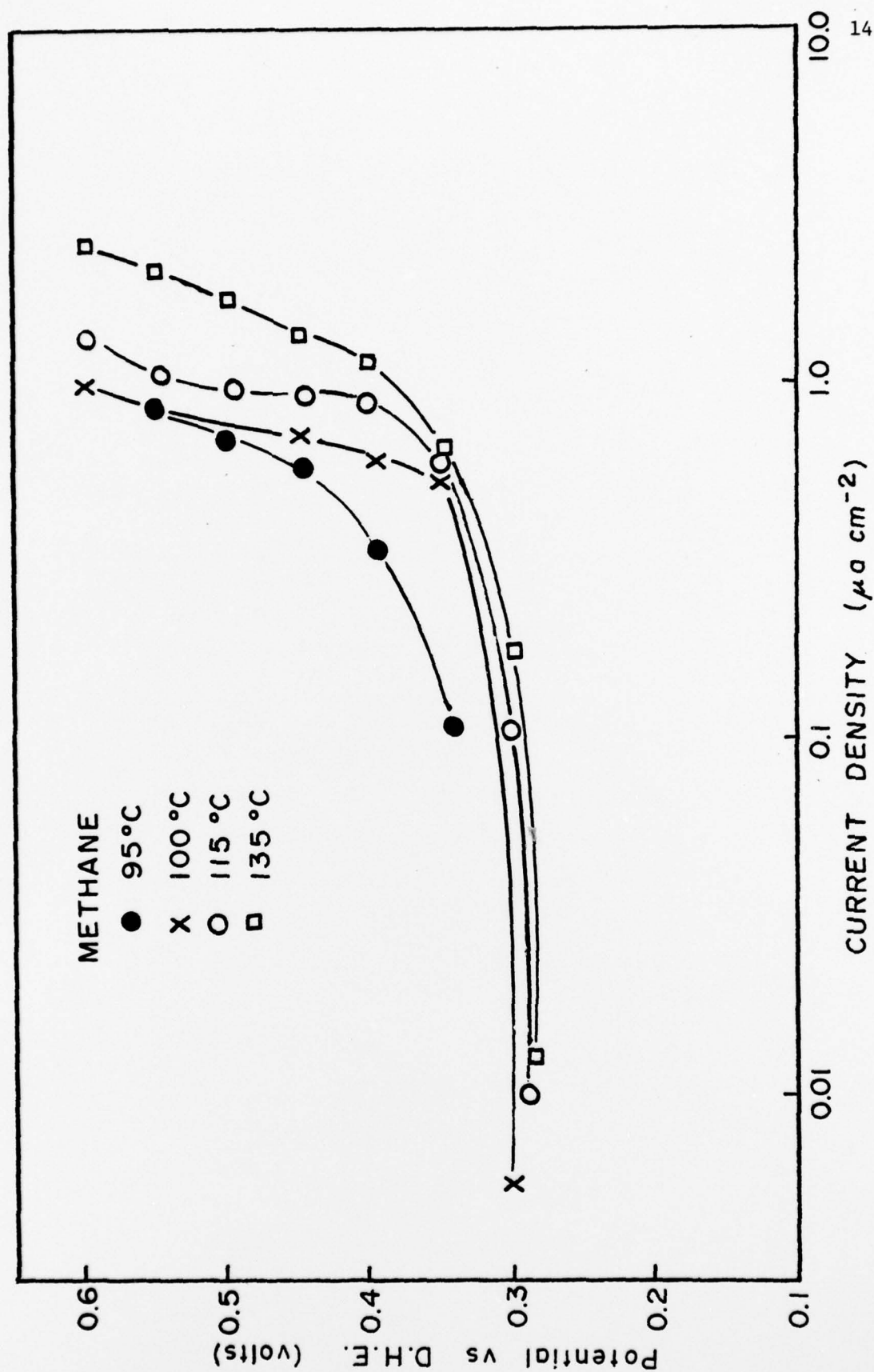
Figure 5. Electrooxidation of Methane in $CF_3SO_3H \cdot H_2O$

14

TABLE I

COMPARISON OF ELECTROCHEMICAL BEHAVIOR OF METHANE,

ETHANE, PROPANE AND n-BUTANE IN TRIFLUOROMETHANESULFONIC

ACID MONOHYDRATE ELECTROLYTE

		Open Circuit Potential	Current Density at 0.5 Volt
CH_4	95°	290 mv	0.71 $\mu a/cm^2$
	100°	285 mv	0.75 $\mu a/cm^2$
	115°	282 mv	0.98 $\mu a/cm^2$
	135°	272 mv	1.7 $\mu a/cm^2$
C_2H_6	85°	295 mv	0.74 $\mu a/cm^2$
	100°	290 mv	1.50 $\mu a/cm^2$
	115°	268 mv	2.20 $\mu a/cm^2$
	135°	265 mv	4.47 $\mu a/cm^2$
C_3H_8	95°	285 mv	2.80 $\mu a/cm^2$
	115°	280 mv	4.50 $\mu a/cm^2$
	135°	272 mv	8.20 $\mu a/cm^2$
$n-C_4H_{10}$	100°	292 mv	1.15 $\mu a/cm^2$
	115°	285 mv	1.55 $\mu a/cm^2$
	135°	278 mv	3.85 $\mu a/cm^2$

16

potential and current density values at 0.5 volt overvoltage for
methane and for the other hydrocarbons evaluated.

Electrochemical behavior of ethane in $CF_3SO_3H \cdot H_2O$

Figure 6 summarizes the results of the electrooxidation of
C_2H_6 at 85°, 100°, 115°, and 135°C. Again, as would be anticipated,
the current densities at each potential rise with increasing temperature.
The shift of open circuit potential over a 50° temperature difference
was about 30 millivolts. At all temperatures the rate of the
electrooxidation of ethane was higher than that for methane. At
135°C, at 0.5 volt, the current density, 4.47 $\mu a/cm^2$, can be compared
with 8.2 $\mu a/cm^2$ for propane in $CF_3SO_3H \cdot H_2O$.

Electrochemical behavior of n-butane in $CF_3SO_3H \cdot H_2O$

Figure 7 summarizes the results for n-butane at 100°, 115°,
and 135°C in $CF_3SO_3H \cdot H_2O$. Results with respect to temperature are
analogous to methane and ethane. There is a shift in open circuit
potential of 14 millivolts over a 35° temperature range for the
reaction as is shown in Table I. The current density levels for the
n-butane reaction are higher than those for methane but lower than
those for propane and for ethane.

Relationship between rate of electrooxidation and hydrocarbon number

The rate of adsorption of methane on a platinum electrode is
known to be very slow and small in quantity. Ethane adsorption is
more rapid and in larger quantities than methane, yielding higher
current densities during the electrooxidation. Propane and n-butane
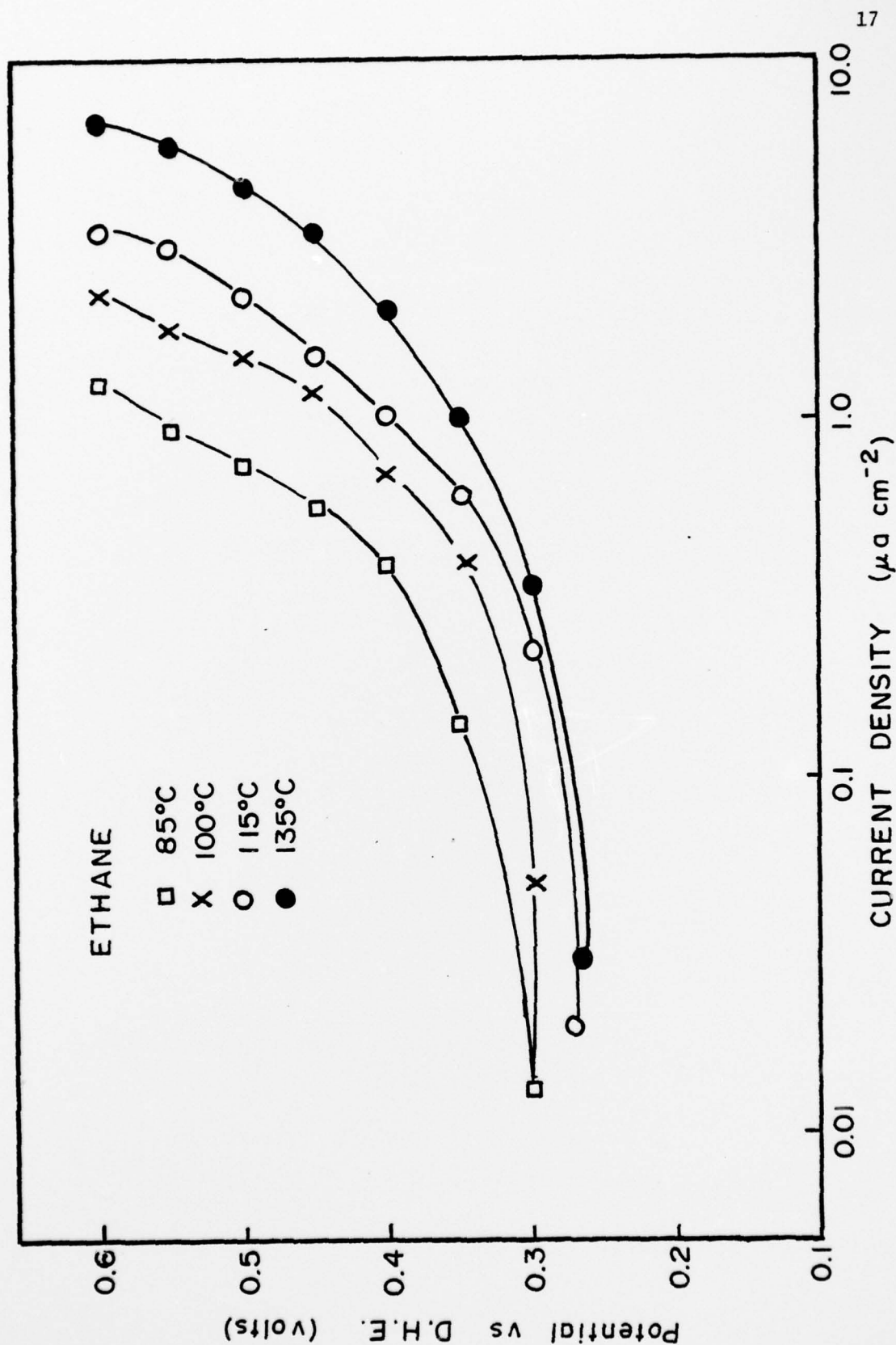adsorb in a way similar to ethane, with adsorption a function of

Figure 6. Electrooxidation of Ethane in $CF_3SO_3H \cdot H_2O$.
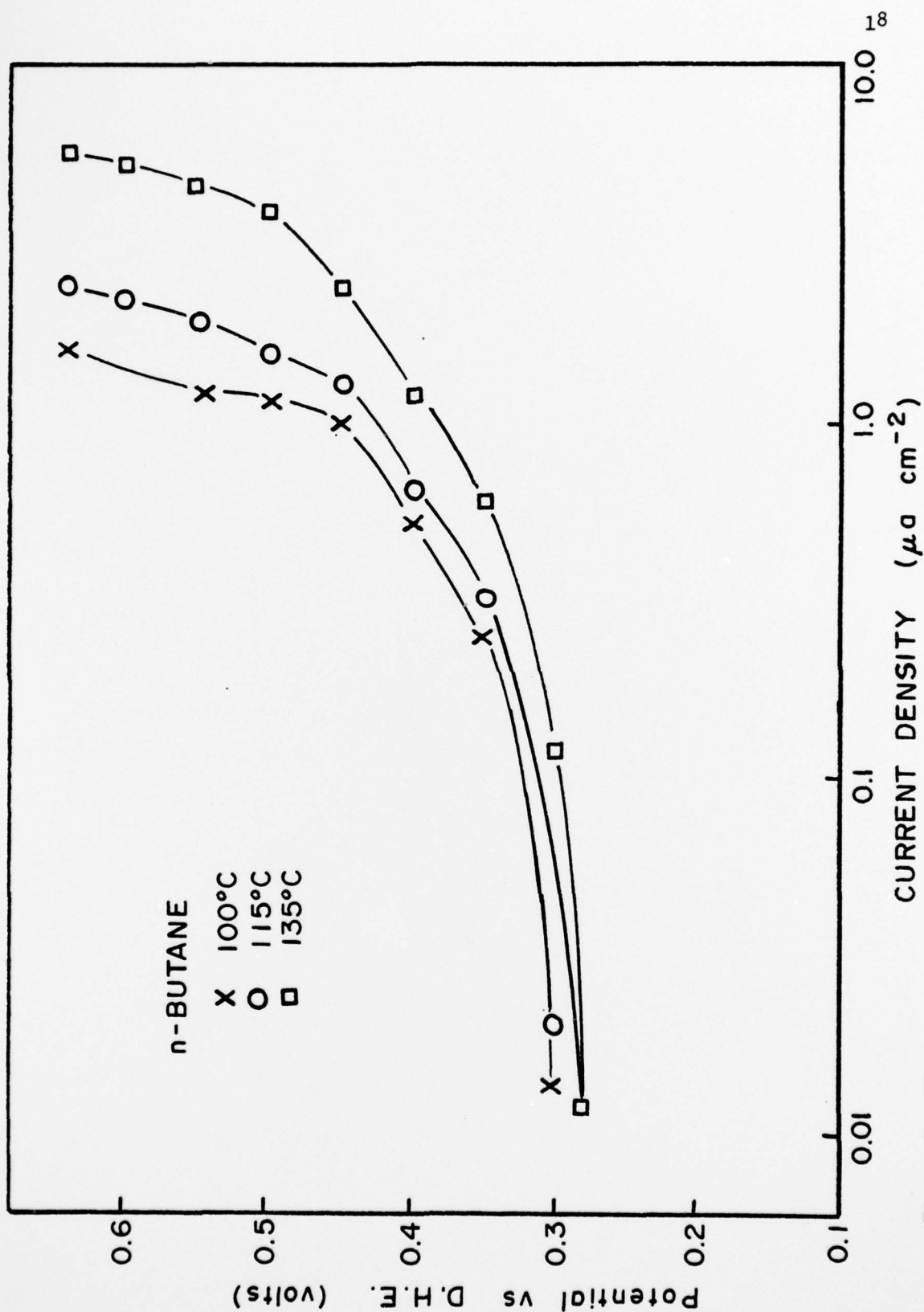
Figure 7. Electrooxidation of n-Butane in $CF_3SO_3H \cdot H_2O$.

temperature.

The materials found on the electrode surface have been termed: Type I (O-type), Type II (CH-α), and Type III (CH-β) (6). Type I is oxidized near 0.7 volt, but is not cathodically desorbable. Type II is oxidized at higher potentials and is cathodically desorbable. Type III is slowly oxidized at high potentials and is not reducible. As the carbon number of the alkane goes up, more of the difficultly oxidizable intermediates are formed, resulting in the observed $C_3H_8 > C_2H_6 > n-C_4H_8 > CH_4$ series in the common inorganic acids such as HF, H_2SO_4, $HClO_4$ and H_3PO_4. It was of interest to determine if the alkane reaction was similar on a comparative base in $CF_3SO_3H \cdot H_2O$.

Figure 8 compares the carbon number of the alkane with the relative current density of the alkane with respect to the current density of propane at 0.5 volt at 135°C. As is evident, propane does support the highest current density in $CF_3SO_3H \cdot H_2O$ for the lower molecular weight hydrocarbons. Referring to Table I and previous results (1), the performance of the electrooxidation would be of the order, $C_3H_8 > C_2H_6 > n-C_4H_{10} > CH_4$. Though the activity of ethane, butane, and methane are quite low the results are still of interest. A similar activity series was observed for the inorganic acid electrolytes previously so the results are of interest mechanistically.

The temperature dependence for the electrooxidation of the four hydrocarbons is given in Fig. 9. The calculated activation energies are given in Table II. These values are about certain to only within $\pm$ 2 kcal considering the short temperature range but they do indicate extremely low values for the reactions.

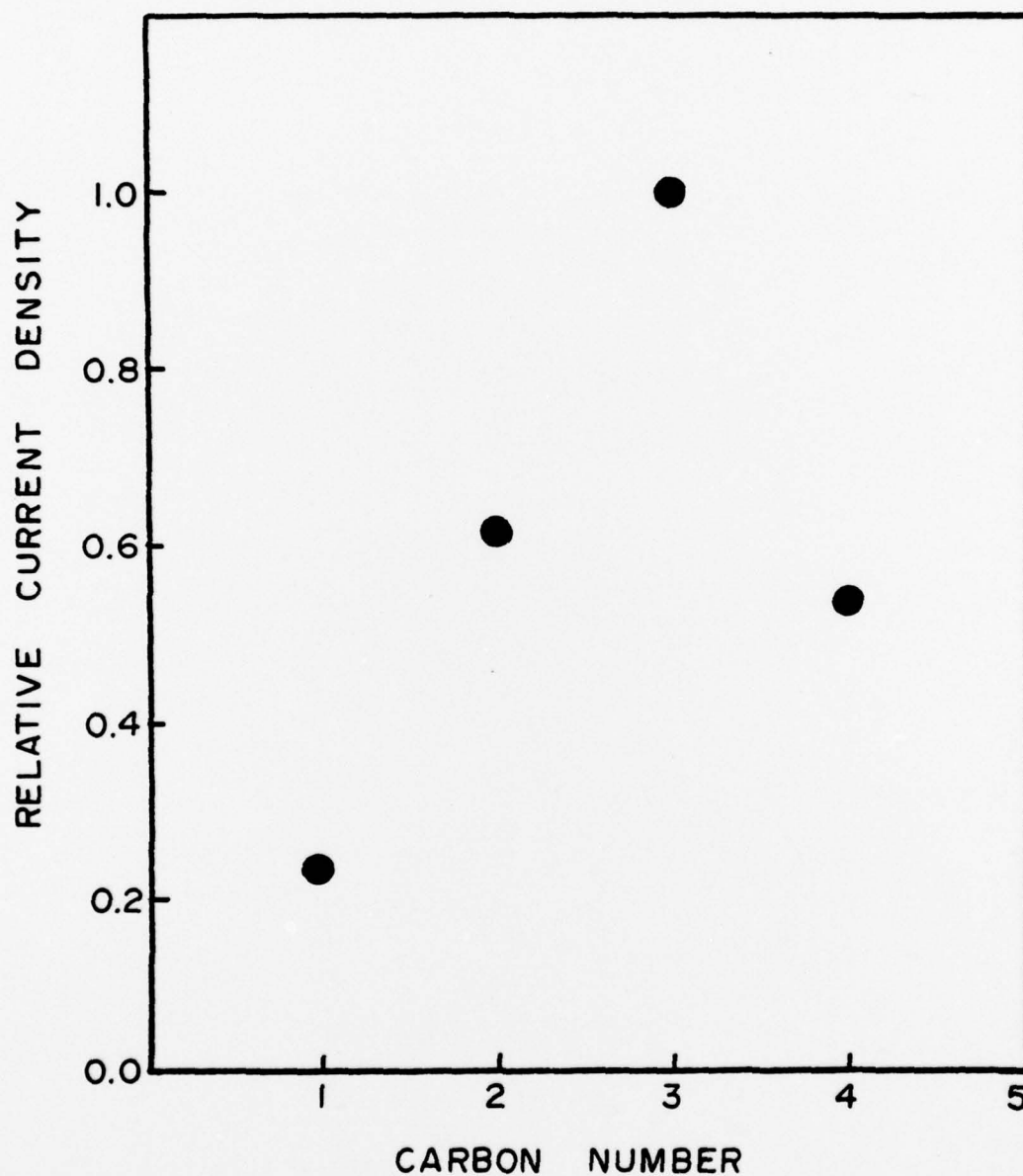Figure 8. Relationship Between Electrooxidation Rate
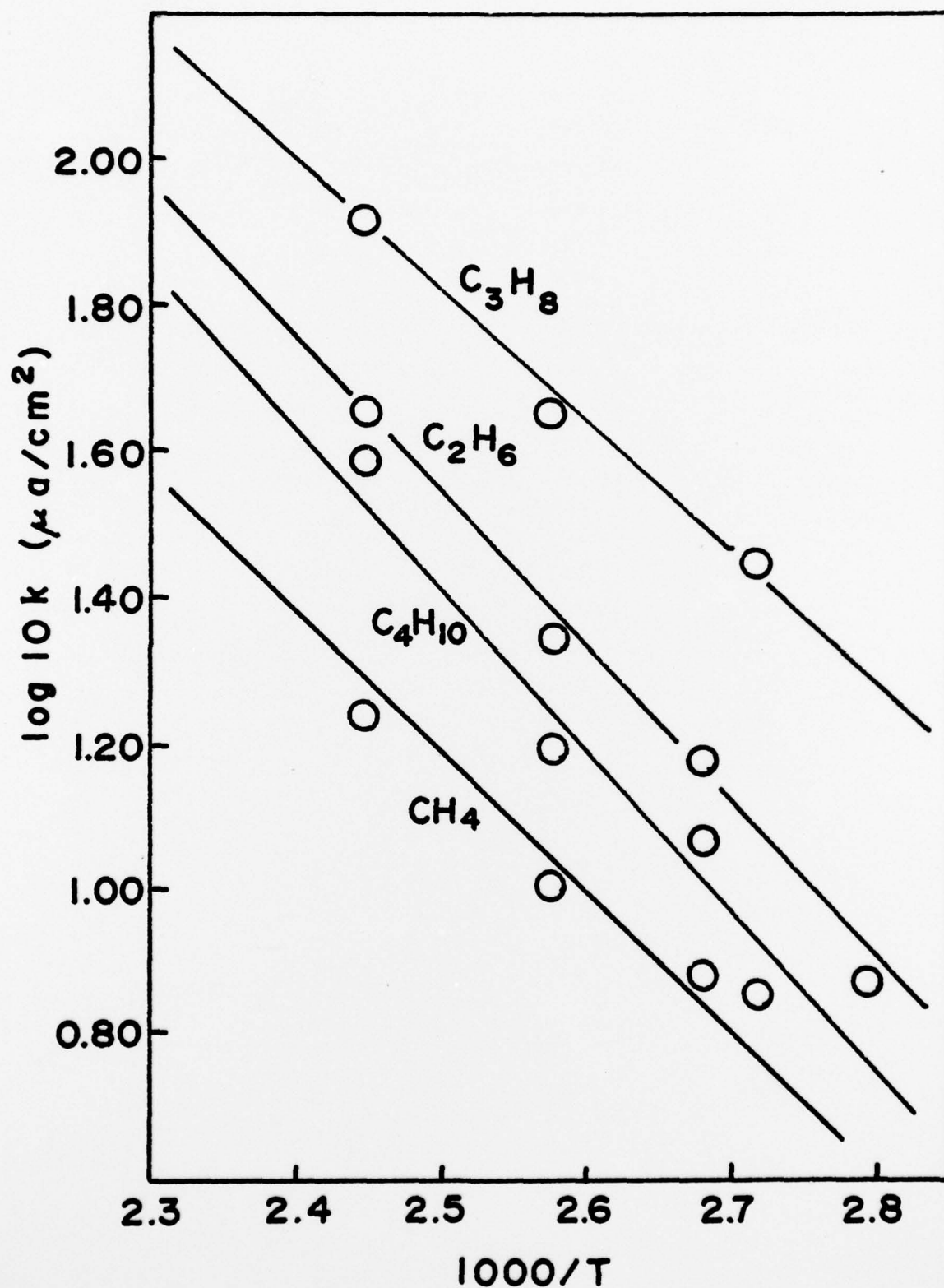and Hydrocarbon Number.

21

Figure 9. Temperature dependence for the electrooxidation of methane, ethane, propane, and butane.

TABLE II

ACTIVATION ENERGIES FOR ELECTROOXIDATION OF HYDROCARBONS

Methane	8.9 k cal mole^{-1}
Ethane	9.8 k cal mole^{-1}
Propane	8.3 k cal mole^{-1}
n-Butane	10.1 k cal mole^{-1}

2.4 Conclusions

These experiments indicate that the electrooxidation rates of the C_1 to C_4 alkanes follow the same relative sequence in trifluoromethanesulfonic acid monohydrate as previously observed in aqueous solutions of HF, $HClO_4$, H_2SO_4, and H_3PO_4. Propane has the highest oxidation rate but the other lower carbon compounds have sufficiently high rates to make them of interest as potential fuel cell reactants.

These results are net rates for an overall reaction that must involve many steps, so very little can be deduced relative to the mechanism of oxidation. These results, however, when coupled with some of the previous results, suggest that in the direct oxidation of these hydrocarbons, less "undesirable" material, such as polymeric species, are produced in the sulfonic acid.

In perspective, there appear to be certain statements that can be made. It is generally considered that the most active (electrochemically) of the hydrocarbons are those in the C_1 to C_4 range. The results reported here confirm the finding with respect to the general utility of trifluoromethanesulfonic acid monohydrate as an improved electrolyte for the hydrocarbon-air fuel cell.

3.0 References

1. A. A. Adams and R. T. Foley, Final Technical Report on Contract
    No. DAAK02-72-C-0084 December 1975

2. E. J. Cairns, "Anodic Oxidation of Hydrocarbons," Advances in
    Electrochemistry and Electrochemical Engineering, Vol. 8,
    Wiley-Interscience, New York, 1971.

3. J. Giner, J. Electrochem. Soc., 111, 376 (1964).

4. S. B. Brummer, J. I. Ford, and M. J. Turner, J. Phys. Chem.,
    69, 3424 (1965).

5. T. Gramstad and R. N. Haszeldine, J. Chem. Soc., 4069 (1957).

6. S. B. Brummer in "Fuel Cell Systems - II," ed. by B. S. Baker,
    American Chemical Society, Washington, D.C., 1969, pp 223-230.

Commander (12)
Defense Document Center
Cameron Station, Building 5
ATTN: TISIA
Alexandria, VA. 22314

Commanding General (1)
Headquarters, U.S. Army Material Command
ATTN: AMCRD-GP, Mr. John M. Horstkamp
5001 Eisenhower Avenue
Alexandria, VA. 22304

Commander (1)
U.S. Army Material Command
ATTN: AMCRD-TE, Mr. John Crellin
5001 Eisenhower Avenue
Alexandria, VA. 22304

Commanding General (1)
U.S. Army Tank Automotive Command
Technical Library
Warren, MI. 48090

Commanding Officer (1)
U.S. Army Electronics Command
ATTN: AMSEL-KL-P, Mr. David Linden
Fort Monmouth, N.J. 07703

Commanding Officer (1)
U.S. Army Transportation Research and
Engineering Command
ATTN: Research Directorate
Fort Eustis, VA. 23604

Chief of Research and Development (1)
Office, Chief of Staff
Department of the Army
Washington, D.C. 20310

Chief (1)
U.S. Army Security Agency
Arlington Hall Station
Arlington, VA. 22212

Office of the Assistant Secretary (1)
of Defense (R&D)
ATTN: Technical Library
Washington, D.C. 20310

Office of Assistant Director (1)
Defense Research & Engineering
ATTN: Col. G.D. McPherson
Pentagon
Washington, D.C. 20310

Power Information Center (1)
University City Science Institute
3401 Market Street
Room 2210
Philadelphia, PA. 19104

Institute of Defense Analysis (1)
400 Army-Navy Drive
ATTN: Mr. Robert Hamilton
Arlington, VA. 22202

Director (1)
National Aeronautics and Space
Administration
ATTN: Code RDP, Mr. E.M. Cohn
Washington, D.C. 20546

Director (1)
George Marshall Space Flight Center
ATTN: M-ASTR-E
Huntsville, AL. 38809

Commanding Officer (1)
Aerospace Power Division
ATTN: AFAPL/PO (Mr. George W. Sherman)
Wright-Patterson Air Force Base
Dayton, OH. 45443

Director (1)
Lewis Research Center
National Aeronautics and Space
Administration
ATTN: Mr. H.J. Schwartz (M.S. 309-1)
2100 Brook Park Road
Cleveland, OH. 44135

Commanding Officer (1)
Rome Air Development Center
ATTN: TUGG, Mr. F.J. Mollura
Griffiss AFB, N.Y. 13440

Commanding Officer (1)
U.S. Air Force Security Service
ATTN: DCS/Communications-Electronics (ESO)
San Antonio, TX. 78241

Chief (1)
Naval Ships Engineering Center
Department of the Navy
ATTN: Code 6157D, Mr. C.F. Viglotti
Washington, D.C. 20360

Director Power Branch (1)
Office of Naval Research
ATTN: Code 473, Dr. Ralph Roberts
800 N. Quincy Street
Arli gton, VA. 22217

Chief (1)
Naval Ship Systems Command
Department of the Navy
ATTN: Mr. B.B. Rosenbaum, Code 03422
Washin ton, D.C. 20360

Office of Naval Research (1)
Department of the Navy
ATTN: Code 425
800 N. Quincy Street
Arlington, VA. 22217

Commandin Officer (1)
Naval Ordenance Test Station
China Lake, CA. 93555

Commanding Officer (1)
U.S. Naval Electronics Laboratory
San Diego, CA. 92152

Director (1)
U.S. Naval Research Laboratory
ATTN: Code 2027
Washington, D.C. 20390

Commanding Officer (1)
Naval Ships R&D Center, Annapolis Division
ATTN: Mr. John H. Harrison
Annapolis MD. 21402

Technical Documents Center (2)
USAMERDC
Fort Belvoir, VA. 22060

Argonne National Laboratory (1)
9700 South Cass Avenue
ATTN: Dr. A. Tevebaugh
Argonne, IL. 60439

Dr. Paul C. Milner (1)
Bell Telephone Laboratories
Murray Hill, N.J. 07974

Mr. Sid y Gross (1)
Mail Stop 88-06
The Boeing Company
P.O. Box 3999
Seattle, Washington 98124

Electrochimica Corporation (1)
2485 Charleston Road
ATTN: Mr. V. Sparks, Technical Library
Mountain View, CA. 94040

Engelhard Industries, Inc. (1)
Military Service Department
113 Astor Street
ATTN: Mr. V.A. Forlenza
Newark, N.J. 07114

Esso Research & Engineering Company (1)
Box 121, ATTN: Dr. G. Ciprios
Linden, N.J. 07036

General Electric Company
950 Western Avenue
ATTN: Mr. L. Nuttall
West Lynn, MA. 01905

Institute of Gas Technology (1)
State and 34th Streets
Technology Center
ATTN: Mr. L.G. Marianowski
Chicagon, IL. 60616

Massachusetts Institute of Technology (1)
ATTN: Prof. H.P. Meissner
Cambridge, MA. 02138

P.L. Howard Associates, Inc. (1)
Millington, MD. 21561

Pratt & Whitney Aircraft Division (1)
United Aircraft Corporation
ATTN: Mr. W.H. Podolny
400 E Main Street
East Hartford, CT. 06108

The Standard Oil Company (1)
Research Center
4440 Warrensville Center Road
ATTN: Dr. Robert A. Rightmire
Cleveland, OH. 44128

TRW Systems (1)
R1/2094
One Space Park
ATTN: Dr. Herbert P. Silverman
Redondo Beach, CA. 90278

UCLA (1)
Department of Chemical Engineering
ATTN: Prof. D. Bennion
Los Angeles, CA. 90007

Union Carbide Corporation (1)
Parma Research Center
P.O. Box 6166
ATTN: Dr. R. Brodd
Parma, OH. 44101

University of Florida (1)
Department of Chemical Engineering
P.O. Box 3027
ATTN: Professor R.D. Walker
Gainesville, FL. 32601

Globe-Union Inc. (1)
ATTN: Corporate Research
5757 North Green Bay Avenue
Milwaukee, WI. 53201

Energy Research Corporation (1)
ATTN: Dr. B.S. Baker
15 Durant Avenue
Bethel, CT. 06801

Mr. Norman Rosenberg (1)
U.S. Department of Transportation
Transportation Systems Center
55 Broadway
Cambridge, MA. 02142

Professor R.T. Foley (1)
Department of Chemistry
The American University
Washington, D.C. 20016

Dr. S.B. Brummer (1)
Director of Physical Research
EIC, Inc.
55 Chapel Street
Newton, MA. 02158

Commanding Officer (1)
Harry Diamond Laboratories
AMXDO-RCB, ATTN: Dr. Morrison
Washington, D.C. 20438

Director Technical Information (1)
Advanced Research Projects Agency
1400 Wilson Blvd.
Arlington, VA. 22209

Dr. D.C. Olson (1)
Shell Development Company
P.O. Box 262
Wood River, IL. 62095

Dr. R.A. Wynveen
President, Life Systems, Inc.
23715 Mercantile Road
Cleveland, OH. 44122

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA. 94304

State University of New York at Buffalo
ATTN: Stanley Bruckenstein, Ph.D.
220 Acheson Hall
Buffalo, N.Y. 14214

Hugh J. Barger, Jr.
Box 2232
Davidson, N.C. 28036